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A PRELIMINARY COST ESTIMATE

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MICROBIAL POLYMERS: A PRELIMINARY COST ESTIMATE

By V. E. Sohns, S. P. Rogovin, and E. L. Griffin, Jr.[1]

A microbial-synthesized polymer discovered at the Northern Utilization Research and Development Division and produced with the bacterium *Xanthomonas campestris* NRRL B-1459 has been evaluated quite extensively by industry. Several companies have produced the polymer in semi-commercial scale. This polymer has a variety of potential applications in food and pharmaceuticals as an emulsifying, thickening, or gelling agent and in the petroleum industry for drilling muds and for secondary recovery of oil. Natural water-soluble gums are used for many of these applications, but such gums for the most part must be imported. Although polysaccharide B-1459 has properties comparable to, and for some applications superior to, those of the plant hydrocolloids, its commercial acceptance depends, among other things, upon the cost at which it is available.

By extrapolation of data obtained from pilot-plant studies on the production of polysaccharide B-1459, preliminary cost estimates have been prepared on its large-scale production. Since the degree of purification of the polymer considerably effects product cost, pilot-plant studies were conducted on both crude and refined products.

Cost information is given on the production of crude polymer by either drum or spray drying the fermented liquor (beer), as well as cost data producing a refined material by either a methanol precipitation process or isolation with a quaternary ammonium compound (QAC).

DESCRIPTION OF PROCESSES

Crude Polymer

The fermentation stage in making polysaccharide B-1459 has been described in detail previously (4)[2] and except for one minor difference is the same for either crude or refined material.

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2/ Underscored numbers in parentheses refer to Literature Cited, p. 15.

The fermentation medium for the crude polymer contains 2.25 percent corn sugar, 0.4 percent distillers' solubles, 0.5 percent dibasic sodium phosphate, and 0.05 percent magnesium sulfate. For a refined polymer, the product has better methanol solubility if 0.5 percent dibasic potassium phosphate is used instead of the sodium salt. With 5.0 percent inoculum at an incubation temperature of 82° F. and an aeration rate of 0.5 volume of air per volume of medium per minute, the fermentation is complete in 96 hours. Solids concentration in the beer is approximately 2.50 percent (moisture-free basis). The final crude product is obtained by drying the whole beer on a conventional double-drum dryer or in a spray dryer (3).

When a drum dryer is used, the steam pressure in the rolls is maintained at about 40 p.s.i.g. (287° F.). For spray drying the whole beer, the respective inlet and outlet air temperatures are 465° F. and 225° F., and the product temperature is about 110° F. Yield of crude product by drum or spray drying is about 21.5 pounds of solids (5 percent moisture) per 100 gallons of beer or 115 pounds of solids per 100 pounds of sugar charged to the process. Polymer constitutes about 60 percent of these solids.

Refined Polymer

Production of refined polymer has been accomplished by recovery of the polymer from the beer either by a methanol precipitation process (4) or by a process involving the use of QAC (1). To recover the polymer by methanol precipitation, the beer, because of its high viscosity of about 7,000 centipoises (cp.) is first diluted with an equal volume of water and then methanol is added to give a concentration of 24.7 percent alcohol. All alcohol concentrations are reported on a weight basis. The slurry, which has a viscosity of 700 cp. or below, is centrifuged to remove cells and suspended impurities. Four percent KCl based on the weight of the undiluted beer and sufficient methanol to give a final concentration of 50 percent are added to the centrifuge. The soft gellike crude polymer that is precipitated is removed by centrifugation. Methanol in this centrifugate is recovered by distillation and reused.

The crude polymer is decolorized and dehydrated by suspending the gum twice in four parts of anhydrous methanol containing 0.1 percent KCl and filtering the slurry to remove the polymer. Concentrations of methanol in the filtrates from the dehydration steps are sufficiently high that these liquors can be used directly for earlier steps in the process when alcohol concentrations of 24.7 percent and 50 percent are required. The final cake is dried in a vacuum dryer to give a product with about 5 percent moisture. Yield of product is about 68 pounds, as-is basis, per 100 pounds of sugar charged to the process.

Recovery of the polymer through the use of QAC includes as the first step, dilution of the fermented broth to reduce its viscosity to at least 450 cp. with two volumes of water, followed by centrifugation of the slurry to remove cells and other suspended matter. Four percent KCl and 2.36 percent QAC by weight (both based on original weight of broth) are added to the centrifugate. The precipitate formed by the addition of QAC is removed by centrifugation with enough of the centrifugate being recycled to the process to dilute beer for subsequent precipitations. Although recycling this centrifugate was not done in pilot-plant studies, it should not introduce any difficulties during plant operations and should reduce KCl requirements considerably. The precipitate is suspended in eight parts by weight of methanol which contains 0.1 percent KCl. After mixing this suspension thoroughly to elute the QAC, it is filtered and the cake resuspended twice more as before to remove the QAC completely. The cake from the last filtration is dried in a vacuum dryer to give a product with 5 percent moisture. Methanol and QAC are recovered separately in an evaporation-distillation system, and both materials are used again. Yield of polymer by this process, just as by methanol precipitation, is about 68 pounds, as-is basis, per 100 pounds sugar charged to the process.

Figure 1 is a simplified flowsheet of the processes for making crude and refined polymers.

COST ESTIMATES

Estimates have been prepared by generally accepted methods for calculating such costs and correspond to early 1964 prices. Delivered cost of individual items of equipment is obtained directly or by extrapolation from published information. Fixed capital investment is estimated by applying appropriate factors to the total cost of delivered equipment to allow for installation, piping, wiring, instruments, etc. and, finally, by adding in amounts for building, land, and improvements. Cost for steam-generating facilities is not included in the fixed capital investment, but a charge of 75 cents per 100 pounds of steam is included in final production costs. Electricity is figured at 1.5 cents per kwh. and water at 10 cents per 1,000 gallons. Items included in the estimated production cost or the "cost to make" are raw materials, utilities, labor and supervision, maintenance, fixed charges, miscellaneous factory supplies and expenses, charge on working capital, and general plant overhead. Fixed charges include depreciation, estimated at 10 percent per year on the total erected equipment cost and 3 percent per year on the building cost, as well as taxes and insurance calculated at 3 percent per year on the fixed capital investment. Maintenance is estimated at 5 percent per year on the total erected equipment cost and 2 percent per year on land and building cost. Labor costs are figured at $3.10 per hour and $2.80 per hour for operators and

helpers, respectively. Cost of the general plant overhead is calculated as 50 percent of the combined cost of labor, supervision, and maintenance.

RESULTS AND DISCUSSION

A preliminary cost study for a plant to produce 5 million pounds per year of crude polymer at 5 percent moisture when operated 300 days per year, 24 hours per day, indicates that at a yield of 21.5 pounds solids (about 60 percent polymer content) per 100 gallons of beer, the cost to make would be approximately 34 cents and 38 cents per pound of drum-dried and spray-dried solids, respectively (table 1). The estimated fixed capital investments (table 2) are $2,410,000 for a plant with drum dryers and $3,110,000 for one with spray dryers. Since a crude product is produced and corrosion should not be a serious problem, steel is considered as a suitable material of construction for such equipment as fermentors, seed tanks, sterilizer, and mixing tanks.

TABLE 1.--Estimated "cost to make" of crude polysaccharide B-1459 in a plant with an annual capacity of 5,000,000 pounds of product (5 percent H_2O). Operations: 300 days per year, 24 hours per day

Cost item	Fermentation stage only	Drum-dried product	Spray-dried product
	Cents/pound	Cents/pound	Cents/pound
Raw materials:			
Corn sugar at 4.0 cents/pound[1]	3.5	3.5	3.5
Other fermentation substrate components	2.4	2.4	2.4
Utilities:			
Steam	.6	4.8	6.2
Water	.2	.3	.3
Electricity	5.4	5.9	6.2
Labor and supervision	2.7	4.7	4.4
Maintenance	1.6	2.2	2.9
Fixed charges	4.1	5.8	7.6
Miscellaneous factory supplies and expenses	.2	.3	.4
Charge on working capital	.3	.3	.4
General plant overhead	2.2	3.5	3.7
Estimated "cost to make"	23.2	33.7	38.0

[1] Price per pound of contained sugar in solution produced by enzymatic hydrolysis of corn.

TABLE 2.--Estimated fixed capital investment for a plant producing 5,000,000 pounds (5 percent H_2O) crude polysaccharide B-1459 annually. Operations: 300 days per year, 24 hours per day

Item	Fermentation stage only	Drum-dried product	Spray-dried product
Land and improvements	$ 30,000	$ 36,000	$ 36,000
Building	200,000	274,000	274,000
Equipment delivered:			
Sterilizer, continuous	2,000	2,000	2,000
Heat exchanger	3,000	3,000	3,000
Pump, positive displacement	2,000	2,000	2,000
3 tanks, inoculum, 125 gallons	3,000	3,000	3,000
5 tanks, seed, 1,200 gallons	15,000	15,000	15,000
18 fermentors with accessories, 23,000 gallons	432,000	432,000	432,000
3 blowers, centrifugal	120,000	120,000	120,000
6 dryers, drum	---	225,000	---
3 dryers, spray	---	---	510,000
Tanks, mixing	14,000	25,000	25,000
Pumps, auxiliary	---	3,000	2,000
Conveyors, storage bins, scales, etc.	9,000	24,000	24,000
Installation of equipment	210,000	300,000	398,000
Piping, wiring, instruments	283,000	404,000	538,000
Engineering and contracting fees	217,000	310,000	415,000
Contingencies	160,000	232,000	311,000
Estimated fixed capital investment	$1,700,000	$2,410,000	$3,110,000

The estimated fixed capital investment (table 2) and estimated cost to make (table 1) for the fermentation stage only in these hypothetical plants are about $1,700,000 and 23 cents per pound of product, respectively. Fermentation or "in-tank" costs include only those incurred during the actual fermentation cycle and exclude any costs related to the recovery phase of the process. Fermentation costs represent about 69 percent of the cost of the drum-dried crude product and 61 percent of the cost of the spray-dried crude product.

If to meet a specific requirement it is necessary to have a crude product substantially free of cells, the cost to make of the crude material is estimated at about 43 cents for a drum-dried product and 47 cents for a spray-dried product. The marked increase in cost of these products as compared to that for crude material from whole beer is due primarily to factors associated with the high viscosity of the beer. It is necessary to dilute the beer with two volumes of water

before the cells can be removed effectively by centrifugation. The centrifugate can then be concentrated to a volume about equal to the original volume of beer, and drying operations can be conducted as before.

Cost estimates for producing refined polymer by either process described earlier are based on a hypothetical plant with an annual capacity of 1 million pounds of polysaccharide at 5 percent moisture. Operations are scheduled for 300 days per year, 24 hours per day. Yield in each plant is 68 pounds, as-is basis, of polymer per 100 pounds of sugar. Estimated costs have been calculated for plants in which stainless steel and stainless-clad steel are the materials of construction for fermentors, seed tanks, filters, and similar units and also for plants in which steel is used to fabricate such units. Detailed cost data for producing refined polymer by the two processes are given in tables3 to 6. A summary of these costs appears in table 7.

TABLE 3.--Estimated fixed capital investment for plant producing 1,000,000 pounds (5 percent H_2O) refined polysaccharide B-1459 by methanol precipitation. Operations: 300 days per year, 24 hours per day

Item	Fermentation stage only		Complete process	
	Steel equipment	Stainless or stainless-clad steel equipment	Steel equipment	Stainless or stainless-clad steel equipment
Land and improvements----------	$ 15,000	$ 15,000	$ 25,000	$ 25,000
Buildings---------------------	144,000	144,000	210,000	210,000
Equipment delivered:				
Sterilizer, continuous------	2,000	5,000	2,000	5,000
Heat exchanger--------------	2,000	5,600	2,000	5,600
Pump, positive displacement	2,000	3,600	2,000	3,600
2 tanks, inoculum, 90 gallons	1,800	3,600	1,800	3,600
3 tanks, seed, 800 gallons--	8,400	18,000	8,400	18,000
10 fermentors with accessories, 15,000 gallons	190,000	320,000	190,000	320,000
2 blowers, centrifugal------	60,000	60,000	60,000	60,000
3 centrifuges, continuous---	---	---	42,000	42,000
4 centrifuges, imperforate basket------------------	---	---	52,000	52,000
2 filters, plate and frame--	---	---	5,000	17,000
Dryer, vacuum---------------	---	---	10,000	17,000
Distillation unit-----------	---	---	65,000	65,000

Table 3.--Continued

Tanks, process and storage	10,000	16,000	75,800	100,600
Pumps, auxiliary	---	---	8,000	10,000
Conveyors, storage bins, scales, etc.	4,000	5,000	9,000	14,000
Subtotal	280,200	436,800	533,000	733,400
Installation of equipment	98,100	152,900	195,000	256,600
Piping, wiring, instruments	132,400	206,300	257,000	347,000
Engineering and contracting fees	101,700	159,500	200,000	243,000
Contingencies	76,600	119,500	150,000	200,000
Estimated fixed capital investment	$ 848,000	$1,234,000	$1,570,000	$2,015,000

TABLE 4.--Estimated "cost to make" of refined polysaccharide B-1459 by methanol precipitation process. Plant capacity 1,000,000 pounds annually Operations: 300 days per year, 24 hours per day

Cost item	Fermentation stage only		Complete process	
	Steel equipment	Stainless or stainless-clad steel equipment	Steel equipment	Stainless or stainless-clad steel equipment
	Dol./lb.	Dol./lb.	Dol./lb.	Dol./lb.
Raw materials:				
Corn sugar at 4.0 cents/ pound[1/]	0.058	0.058	0.058	0.058
Other fermentation substrate components	.076	.076	.076	.076
KCL	0	0	.042	.042
Methanol	0	0	.164	.164
Utilities:				
Steam	.011	.011	.135	.135
Water	.003	.003	.027	.027
Electricity	.090	.090	.115	.115
Labor and supervision	.057	.057	.249	.249
Maintenance	.038	.057	.071	.094
Fixed charges	.099	.149	.187	.245
Miscellaneous factory supplies and expenses	.006	.008	.011	.014
Charge on working capital	.006	.006	.015	.015
General plant overhead	.047	.057	.160	.172
Estimated "cost to make"	0.491	0.572	1.310	1.406

[1/] Price per pound of contained sugar in solution produced by enzymatic conversion of corn.

TABLE 5.--Estimated fixed capital investment for plant producing 1,000,000 pounds (5 percent H_2O) refined polysaccharide B-1459 by isolation with quaternary ammonium compound.[1/] Operations: 300 days per year, 24 hours per day

Item	Steel equipment	Stainless or stainless-clad steel equipment
Land and improvements	$ 25,000	$ 25,000
Building	210,000	210,000
Equipment delivered:		
Sterilizer, continuous	2,000	5,000
Heat exchanger	2,000	5,600
Pump, positive displacement	2,000	3,600
2 tanks, inoculum, 90 gallons	1,800	3,600
3 tanks, seed, 800 gallons	8,400	18,000
10 fermentors with accessories, 15,000 gallons	190,000	320,000
2 blowers, centrifugal	60,000	60,000
3 centrifuges, continuous	42,000	42,000
3 centrifuges, imperforate basket	39,000	39,000
3 filters, plate and frame	6,900	25,500
Evaporator-distillation unit	18,000	18,000
Dryer, vacuum	10,000	17,000
Tanks, process and storage	52,700	74,400
Pumps, auxiliary	9,300	13,300
Conveyors, storage bins, scales, etc.	9,000	14,000
Subtotal	453,100	659,000
Installation of equipment	158,500	231,000
Piping, wiring, instruments	214,000	312,000
Engineering and contracting fees	165,600	242,000
Contingencies	123,800	181,000
Estimated fixed capital investment	$1,350,000	$1,860,000

1/ Estimated fixed capital investment for fermentation stage same as in methanol precipitation process.

TABLE 6.--Estimated "cost to make" of refined polysaccharide B-1459 using QAC for product recovery.[1] Plant capacity 1,000,000 pounds annually. Operations: 300 days per year, 24 hours per day

Item	Steel equipment	Stainless or stainless-clad steel equipment
	Dol./lb.	Dol./lb.
Raw materials:		
Corn sugar at 4.0 cents/pound[2]	0.058	0.058
Other fermentation substrate components	.076	.076
KCl	.016	.016
Methanol	.113	.113
QAC	.006	.006
Utilities:		
Steam	.056	.056
Water	.013	.013
Electricity	.108	.108
Labor and supervision	.207	.207
Maintenance	.060	.086
Fixed charges	.158	.225
Miscellaneous factory supplies and expenses	.009	.013
Charge on working capital	.015	.015
General plant overhead	.134	.147
Estimated "cost to make"	1.029	1.139

1/ Estimated cost to make for fermentation stage same as in methanol precipitation process.

2/ Price per pound of contained sugar in solution produced by enzymatic hydrolysis of corn.

TABLE 7.--Comparison of estimated costs for producing refined polymer by the methanol precipitation or QAC isolation processes[1/]

Process	Fixed capital investment: Steel equipment	Fixed capital investment: Stainless or stainless-clad steel equipment	"Cost to make": Steel equipment	"Cost to make": Stainless or stainless-clad steel equipment
Fermentation stage only[2/]----------	$ 848,000	$1,234,000	$0.49 per lb.	$0.57 per lb.
Methanol precipitation---	1,570,000	2,015,000	1.31 per lb.	1.41 per lb.
QAC isolation----	1,350,000	1,860,000	1.03 per lb.	1.14 per lb.

1/ Costs based on hypothetical plants with annual production capacity of 1 million pounds of polymer when operating 300 days per year, 24 hours per day.

2/ Costs for fermentation stage are same in both processes.

Losses of methanol and QAC in all cases are estimated at 2 percent and 1 percent, respectively. All the KCl in the methanol precipitation process is lost, but of the KCl used in the QAC isolation process only 36 percent is lost. Previously it has been suggested that in plant operations the supernatant from the initial isolation of QAC-precipitated material, which contains most of the KCl charged to the process, can be recycled and used for diluting the beer at the start of recovery operations; however, only about two-thirds of the supernatant can be so used.

Difference in the estimated costs to make for the refined polymer by the two methods described is attributable largely to the difference in the respective charges for recovering the methanol. Approximately 19 gallons of methanol are required per pound of product in the QAC isolation process as compared to 27.5 gallons in the methanol precipitation process. The spent alcohol from the latter is also more dilute than that when QAC is used. Of the two processes, therefore, the costs per pound of product for alcohol lost in process and distillation of spent alcohol are higher when the polymer is precipitated with methanol.

Corn sugar for this fermentation can be either commercial crystalline dextrose or a dextrose solution prepared by the enzymatic hydrolysis of corn. Both work equally well in the polymer fermentation. Enzymatically produced sugar solutions are being offered by at least one industrial source,

and it is estimated that such a liquor can be available at the fermentation site for about 4 cents per pound of contained sugar. A variation in the price of sugar of 1 cent per pound changes the cost to make the crude polymer and the refined products about 0.9 cent and 1.5 cents per pound, respectively.

The high viscosities of the polymer solutions create a variety of problems which, to some degree, increase production costs of the crude and refined products. With present techniques, the concentration of polymer in the beer is limited to about 1.5 percent. Fermentor capacity per pound of product is large therefor as compared to many other fermentation processes. Dryer requirements, that is, the evaporative capacity needed per pound of crude product, are also considerable since 1 pound of product requires the removal of about 37 pounds of water. Finally, because relatively dilute solutions or suspensions must be processed when refined products are recovered, the volume of liquid that must be centrifuged and the quantity of alcohol used to recover a pound of product are both substantial.

COMPARISON OF PRODUCTS

For many of its potential uses, the polymer is evaluated primarily on the basis of its viscosity characteristics. A comparison of viscosity characteristics of the crude and the refined products shows that in aqueous solutions containing the same actual polymer concentration, viscosities of the various products described are in the same range. On a viscosity basis only, therefore, the crude products are cheaper than the refined.

For some applications in which purity of product would be an important consideration, a refined polymer would probably be used. Chemical characterization of the two refined products indicates that these materials are similar and have about equal purity. Rat and dog feeding tests with the product recovered by alcohol precipitation gave no untoward reactions.[2] Unpublished results from rat feeding tests with crude products from whole beer and also the QAC polymer indicate no untoward reactions from such materials.

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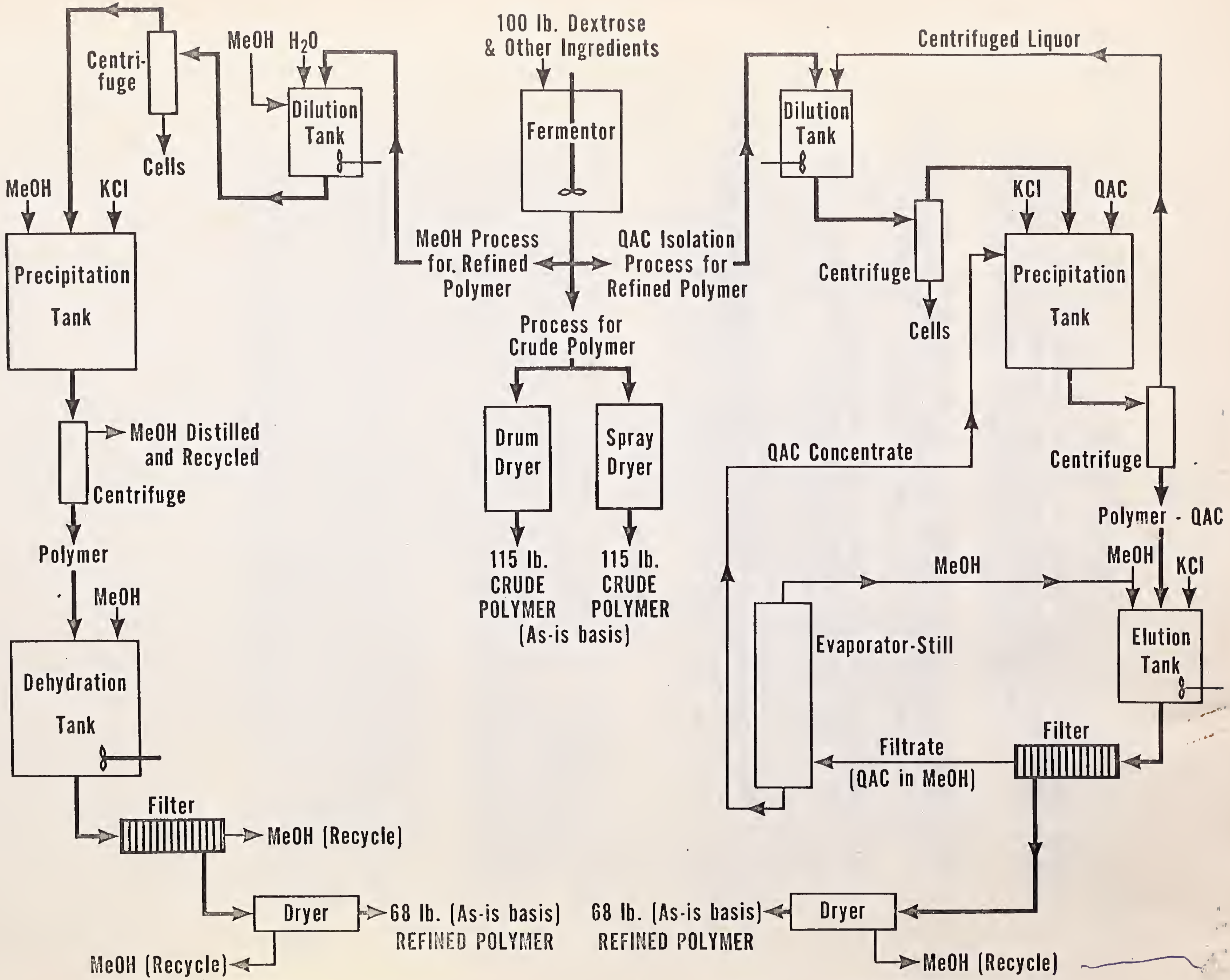

Figure 1.--Flowsheet for production of crude and refined polymer.